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Financial economic scenario for the microgeneration of electric energy from swine culture-originated biogas

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ABSTRACT

One of the largest sources of energy available in rural and agro-industrial areas is the biomass, which is found in the form of vegetal and animal residues, such as crop leftovers, animal manure, energetic plantations and agro-industrial effluents. Such residues may be used by rural producers or agro-industries for direct burning, aiming to produce heat or biogas in biodigesters. Swine production generates a large amount of manure that causes environmental issues when not treated properly, due to its high levels of methane. When it is released in the atmosphere, it expressively contributes to the greenhouse effect. The co-generation of electric energy is still one of the ways to utilize biogas generated from food production. Apart from generating energy, it is also possible to sell carbon credits, what provides the producer with higher income. The present work aimed to determine the cost of installation, as well as the feasibility of biogas-based electricity production, by studying the scale economy in several scenarios of swine, biogas and electric energy production, sale or not sale of carbon credits, and investment costs with the estimated amortization period. One can notice that when carbon credits generate profit, production costs decrease and the LPV (Liquid Present Value) increases. Energy production only leads to loss when there is no additional income with carbon credits.

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Contents

1. Introduction

For the next decades, there are expectations of crisis in the energetic sector, due to the mismatch between demand increase and the inability for the supply to follow the expansion rhythm of the global Gross Domestic Product (GDP), especially oil, which is the base of the national energetic matrix. The immediate and perceptible result of such crisis is volatility and records in the price of oil barrels. Thus, countries aim to relieve uncertainties and also avoid that their economies fall before the energetic crisis, so they foster renewable energy sources such as biomass, solar and wind energy [1].

With the value increase of conventional energy sources along with the growing concern about the future of energy supply, energetic safety took an important position in the politic field all over the world, including Brazil, which is known for its renewable energy sources and has also drawn attention of developed countries due to its sources of clean energy biofuels and electric energy production. The country shows tradition in the use of renewable

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sources of energy, such as hydroelectric energy, which stands out as the responsible for the higher portion (65.32%) of all electricity generation. Other sources of renewable energy have also been taking place in the national scene, such as the biomass, which already corresponds to 7.59% of the energetic matrix, just behind hydroelectric energy, natural gas and oil [2].

Manure-based biogas production contributes to environment protection, by reducing CO_2 emissions through the replacement of fossil fuels and reduction of methane (CH_4) emissions [3]. Besides the produced biogas, anaerobic digestion transforms the raw material added to the biodigester into fertilizer to be used in agricultural production. The degradation process increases nitrogen availability in the plant, what also increases raw material fertilization efficiency [4].

Biogas produced trough anaerobic digestion is basically composed by methane (CH_4), carbon dioxide (CO_2), and hydrogen sulfide (H_2S). Anaerobic digestion is a natural process in which anaerobic bacteria attack the structure of organic matter in order to produce simple compounds, as methane, carbon dioxide and water, forming biogas, which contains approximately 36 to 50% of methane (CH_4) and 15 to 60% of carbon dioxide (CO_2) [5–7]. It also has lower levels of other contaminants, such as hydrogen sulfide, nitrogen, water, oxygen, ammonia and siloxanes. The concentration of each compound varies depending on the gas source and their composition. As an example, residues with higher organic concentration lead to biogas with higher methane content [8].

Different types of residues have potential to produce biogas, such as: bovine and swine manure, sewage sludge, fruit and vegetable residues, and so on [9]. According to [10], the advantages of biogas units are many, such as: economically attractive investment, ease of operation and conservation, possibility of producing electric energy in a renewable way reducing CO_2 emission, reduction in methane emission from the storage of animal manure, and use of biofertilizers in crops, what decreases production costs. The disadvantage of using biogas is the difficulty of storage volume of inert gas (CO_2), low calorific value and lower corrosion great power [11].

The extension of renewable energy production is clearly an imperative; however, its construction is only economically feasible if the operation results, in long terms, in sustainability [12]. The utilization of biomass gas in the generation of electric energy aims to reduce costs in energy production and decrease the emission of greenhouse effect gases, as well as to increase electric energy supply in Brazil. States that biogas-based energy generation has great potential to boost local economy, fostering important sectors, such as industry, business and services [13].

Energy generation with the use of swine manure is still rare in Brazil, even being a way of reducing pollution and environmental degradation around poultry farms. However, the current system is favorable to its development, due to the cycle of high prices of oil, fossil fuels and natural gas—what makes this kind of modality become feasible, disregarding the growing pressure for the decreasing of environmental degradation associated with the production of food.

Residues originated from animal creation, such as aviculture and swine culture, have large potential to pollute. Traditionally, such residues have been cast directly to the soil as fertilizers, but in some situations such method may cause environmental problems, as unpleasant odor and water contamination. Two options were studied for these types of residues in Europe: one is anaerobic digestion of swine culture residues, and the other is direct burning, with the use of aviary bedding [14].

The burning of 1 t of methane is equivalent to the elimination of 21 t of [15]. Credits negotiated in Chicago Climage Exchange (CCX) varied in relation to 2008, from US$1.90/ton to US$7.40/ton, with an average price of US$4.98 per carbon ton [16]. Data used by [15] show that by the end of February 2012, the value paid for each ton, with delivery in 2013, reaches US$14.50.

2. Methods

Colombari Poultry Farm is located at Linha Marfim, in the municipality of São Miguel do Iguaçu, latitude 25°20'53 South and longitude 54°14'16 West, in the state of Paraná. It works with confined creation system. Biomass generation is directly linked to handling factors, water supply system, conditioning and cleaning systems. There are two biodigesters: one with capacity of 29.2 m³ and retention period of 30 days; and another with 7.3 m³ and hydraulic retention of 20 days. In the output tubing, the effluent is directed to a dunghill that stores the biofertilizers, which will be used in crops.

The generation of electric energy is accomplished with the use of a motor-generator set with 100 kVA, protection system and command board. It is interconnected to the distribution network, for the commercialization of the excesses. The motor-generator set consumes 50 m³ h^{-1} and its rotation is 1800 RPM.

For financial analysis purposes, the energy generation period was varied, and consequently, the amount of swine, biogas production, initial investment cost and payback period.

2.1. Determination of financial parameters and production cost Ćof electric energy.

Scenario 1—Current situation of Colombari Poultry Farm: Average biogas production is 554 m³ $day^{-1}$for an average of 4673 pigs housed at an average temperature of 22.11 °C. Motor-generator set data, as provided by the manufacturer, are: power–76 kW, and biogas consumption–50 m³ h^{-1}. Data collected about the motor-generator set's working are: average power–66.22 kW, and specific biogas consumption–45.55 m³ h^{-1}. Real working data will be used in this study for calculation purposes. Energy generation happens for 10 hours/day. Biodigester cost is US$ 146.283,33 and motor-generator set cost is US$ 56.383,14

Scenario 2—Simulates that energy generation happens during 16 hours/day. In that sense, biogas production will be 729 m³ day^{-1} and, simultaneously, swine production will reach 6073 animals. Power and motor consumption are considered the same in all 3 scenarios. Biodigester cost will be US$ 175.182,48. Motor-generator set cost, for calculation purposes, will be US$ 56.383,14.

Scenario 3—Simulates 20 hours/day of energy generation, with 911 m³ day^{-1} of biogas, and swine production of 7000 animals. Biodigester cost in this scenario is US$ 218.978,10 and motor-generator set cost is US$ 56.383,14.

Commercial values of the biodigester (including excavation and complete installation) were provided by Sansuy—PVC solutions. Motor-generator set values were provided by ER-BR Energias Renováveis.

In all three scenarios the electric energy production cost was calculated. The parameters for economic assessment of projects will be exposed by means of LPV—Liquid Present Value (or VPL, in Portuguese), IRR—Internal Rate of Return (or TIR), and payback period (or TRI).

Liquid Present Value (VPL) → makes a comparison between the investments performed and present value in cash flows generated by the project. All cash flows are considered, not only the moment in time when the accumulated balance becomes positive. It can provide an average of added wealth (VPL>0) or destructed wealth (VPL<0). The interest rate used for parameter definition will be

5.5%/year, as imposed by the ABC Program. VPL is given by:

$$VPL = -I + \sum_{t=1}^{n} \frac{FC_t}{(1+r)^t} + \frac{VR}{(1+r)^n} \tag{1}$$

In which:

$I \rightarrow$ Initial investment;
$FC_t \rightarrow$ Liquid cash flow on date t;
$r \rightarrow$ Capital cost;
$VR \rightarrow$ Residual value of the Project at the end of the analysis period.

Internal Rate of Return (*TIR*)→It is a reference used to define acceptance or not of a project. The internal rate of return makes *VPL* null.

Payback period (TRI)→In order to calculate it, the value paid to the producer per M Wh produced was simulated in US$ 59,59–US$ 69,52–US$ 79,45–US$ 89,38–US$ 99,31–US$ 109,24, because, according to [2], the value paid for biomass-originated energy is US$ 71,60 per M Wh. As for feasibility analysis, the value considered will be US$ 69,52 M Wh^{-1}. Equations were adapted from [14].

$$TRI = \frac{\ln(k/kx(1-j)^{-1}-J)}{\ln(1+j)} \tag{2}$$

In which

$$k = \frac{A}{CI} - \frac{OM}{100}$$

CI–Investment cost in the biodigester/motor-generator set (US$), *A*–Annual expenses with electric energy acquired in the network (US$ $year^{-1}$), *OM*–Expenses with amortization and maintenance of the plant (US$ $year^{-1}$), *TRI*–Payback Period (years).

Electric energy cost:

$$C_e = \frac{CAG + CAB}{PE} \tag{3}$$

In which

C_e–biogas-originated electric energy cost (US$ kWh^{-1}), *CAB*–Annual expenses with biogas (US$ $year^{-1}$) and *PE*–Electricity production by the biogas plant (kWh $year^{-1}$), *CAG*–Annualized cost of the investment in the motor-generator set (US$ $year^{-1}$).In which:

$$CAG = CIG.FRC + \frac{CIG.OM}{100} \tag{4}$$

$$CAB = CB.CNB \tag{5}$$

In which:

CIG–Investment cost in the motor-generator set (US$), *OM*–Costs of organization and maintenance (%/year), *CB*–biogas cost (US$ m^3) and *CNB*–Biogas consumption by the motor-generator set (m^3 $year^{-1}$). Electricity production (*PE*) is given by

$$PE = Pot.T \tag{6}$$

Pot–Nominal Plant Power (kW), *T*–Annual plant availability (hours $year^{-1}$). Capital Return Factor is given by

$$FRC = \frac{j(1+j)^n}{(1+j)^{n-1}-1} \tag{7}$$

FRC–Capital Return Factor, *j*–Discount rate (% year), and *n*–years to amortize the investment. Biogas cost is given by

$$CB = \frac{CAB}{PAB} \tag{8}$$

CAB–Annualized cost of the biodigester investment (US$ $year^{-1}$) and *PAB*–Annual production of biogas (m^3 $year^{-1}$).

$$CAB = CIB\ FRC + \frac{CIB.OM}{100} - CC \tag{9}$$

CIB–Biodigester investment cost (US$) and *PAB*–Annual production of biogas (m^3)-*CC*—Carbon credits profit (US$ $year^{-1}$).

In order to convert methane quantity in carbon credits, the following equation was used (10).

Conversion of biogas into t CO_2 and converted to US$ t^{-1}
For such conversion, the following parameters were used:
Biogas production in m^3 $year^{-1}$ (Pr)
CH_4 density: Methane density: 0.67 kg m^{-3} in the temperature of 20 °C at 1 atm of pressure [17,18].
Percentage of methane in the biogas: 60%; (Pc)
Value per t of CO_2: US$ 14,50.
Equivalence between CH_4 and CO_2 –1 unit of CH_4 is equivalent to 21 units of CO_2. (Un)

$$\text{ton } CO_2 = \frac{Pr \times Ds \times Pc \times Un}{1000} \tag{10}$$

$$valor\ da\ ton = ton\ CO_2 \times R \tag{11}$$

3. Results

Fig. 1 shows variations of the Payback Period, according to the hours of energy production and the value paid by the energy concessionaire. With production of 10 h day^{-1} without the sale of carbon credits, payback period is around 27.5 years, when the value paid for MWh is US$ 69,52 With carbon credits sale revenue, the payback period is reduced to 8.5 years.

With production happening 16 h day^{-1}, the payback period without the sale of carbon credits is around 18 years. With the sale of carbon credits, the payback period decreases to 6 years, considering the value paid of US$ 69,52 M Wh^{-1}, as shown in Fig. 2.

When the production of energy happens 20 h day^{-1}, the payback period without the sale of carbon credits is 14 years. With the sale of carbon credits, the payback period is 6 years.

With the sale of carbon credits, the payback period is basically the same when generating either 16 h day^{-1} or 20 h day^{-1}. Thus, it is worth for the producer to generate only 16 h day^{-1}, for the initial investment is lower.

With the sale of carbon credits, producing 10 h day^{-1}, the electric energy production value (US$ 62,62 M Wh^{-1}) becomes feasible with an average payback period of 15 years. With 16 h day^{-1}, in 10 years the production cost (US$ 64,65 M Wh^{-1}) becomes competitive in the energy market.

By selling carbon credits, energy production costs decrease sharply. With a payback period of 10, 15 and 20 years, producing

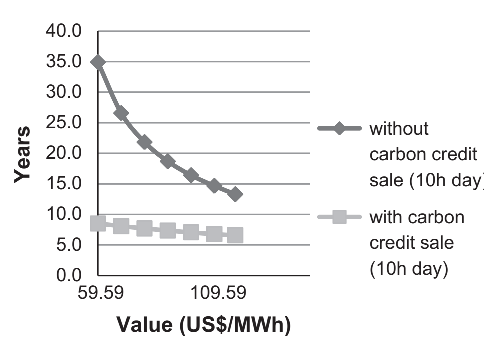


Fig. 1. Payback period.

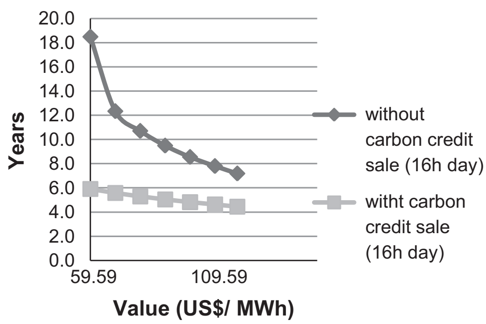


Fig. 2. Payback Period.

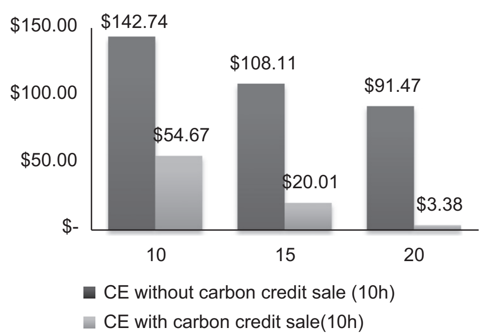


Fig. 3. Electric energy generation cost—10 h day^{-1}.

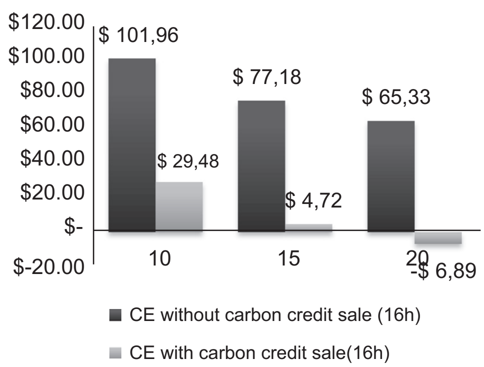


Fig. 4. Energy Production Cost—16 h day^{-1}.

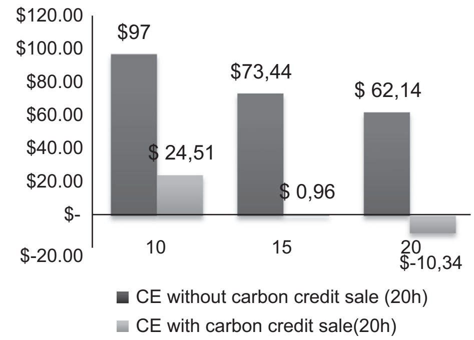
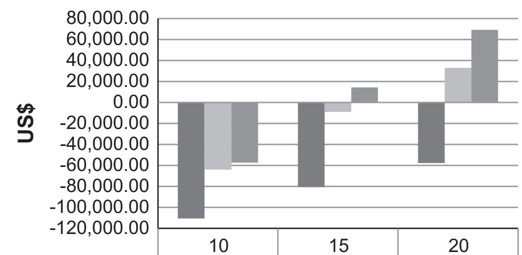
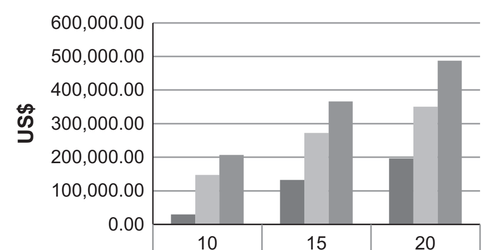


Fig. 5. Electric Energy Cost—20 h day^{-1}.



	10	15	20
10h day	-110,643.57	-80,745.93	-57,841.21
16h day.	-64,014.21	-9,016.85	32,935.65
20h day	-57,223.28	14,347.26	69,108.34

Fig. 6. LPV according to Payback period and operation of the motor-generator set, considering the total value of the biodigester without the sale of carbon credits.



	10	15	20
10h day	30,335.43	132,925.16	196,547.90
16 h day	147,216.73	272,190.87	350,679.66
20h day	206,815.39	365,957.92	487,723.33

Fig. 7. LPV according to the Payback period and operation of the motor-generator set, considering the total value of the biodigester with the sale of carbon credits.

for 10, 16 and 20 h day^{-1}, there is a decrease of about 60% in costs with the sale of carbon credits. Producing 10, 16 and 20 h it is possible to earn US$ 11.215,55–US$ 14.764,91–US$ 18.456,14 with carbon credits, respectively.

Fig. 3 shows the cost variation of electric energy according to the sale or not of carbon credits. With the energy production in 10 h day^{-1}, without selling carbon credits, with an estimated payback period of 10, 15 or 20 years, energy production cost, US $ 142,94, US$ 108,11 and US$ 91,47 respectively, is higher than that paid by the energy concessionaire (US$ 69,52 M Wh^{-1}). With the sale of carbon credits, production costs decrease sharply. With payback period of 10 years, the cost is US$ 54,67 for each M Wh produced. With a payback period of 20 years, by having revenue with carbon credits, the cost is US$ 3,38, in other words, a profit of US$ 66,11 per M Wh.

As shown in Fig. 4, the cost of energy production without the sale of carbon credits, with 10, 15 or 20 years is US$ 101,96, US$ 77,18 and US$ 65,33 respectively. With the revenue of carbon credits, production costs decrease to US$ 29,48, US$ 4,72 e US$ -6,89 respectively. The negative value in the case in which generation happens 20 h day^{-1} and the payback period is 20 years means that the producer will have no cost to produce electric energy, having 100% profit with the production.

When the daily production period is 20 h, the value of production per MWh decreases in relation to other ways of production exposed in Figs. 3 and 4. Without the sale of carbon credits, it is possible to obtain profit with a payback period of 20 years. When the revenue of carbon credits interferes in production value, in 10 years it becomes possible to generate profit with the production of electric energy (Fig. 5).

Fig. 6 presents negative LPV (VPL) in several situations, considering the total value of the investment. LPV becomes positive as from the situation in which the payback is 15 years and the operation happens 20 h day^{-1}. However, LPV becomes negative again when energy generation happens 10 h day^{-1} with payback period of 20 years. From then on, LPV is positive once again. That is, in most of the analyzed situations, the producer will have loss when producing energy originated from swine culture biogas.

Fig. 7 represents the LPV according to the Payback period, considering the total value of investment with the sale of carbon credits.

When there is income with the sale of carbon credits, producers have no loss in any of the studied situations. Any of their choices of energy production will provide profit. That happens because the carbon market is an area in expansion all over the globe, as well as for its contribution to the environment and for generating profit to small and large food producers. It does not contemplate only animal creation, but all sources of renewable energy in general.

4. Discussion

[19], when analyzing the collection of manure for the production of biogas to be used in residences, noticed that when the payback period was 20 years, the LPV was positive, considering a discount rate of 4%.

According to [19], the enterprise becomes feasible when the property has a production capacity of 200 m^3 day^{-1} of gas, what generates an approximate production of 300 kVAh day^{-1} [20,21] when analyzing the feasibility of biogas plants, observed a mix of relevant variables: economic efficiency of anaerobic digestion, among others, such as investment cost, cost of exploration of biogas units, and methane production.

In a study on the feasibility of gas production for the generation of electric energy, in dairy plants, noticed that the production of electric energy was not feasible (US\$0.12 k Wh^{-1}) for small dairy plants. It was not feasible either for small producers of swine to produce biogas, just as small dairy plants (US\$0.12 k Wh^{-1}) [22,23]. [24] when studying the use of biogas in residences in Ethiopia, found a return rate of approximately 10%, with biogas plants able to produce 6 m^3, using animal waste.

[25] studied the economic feasibility of the use of a generator providing 40 KWh, using biogas from swine cultures, and concluded that such alternative is feasible as demands and energy prices increase. With a fare of US\$ 99,31 M Wh^{-1}, the return on investment, considering the discount of interest rate, was 39, 26 and 19 months for the following daily periods of energy generation respectively: 10, 14 and 18 h.

[23] when analyzing the production of biogas originated from swine and cattle in properties of different sizes, concluded that if there is no public stimulus, it is not economically feasible, for the payment of energy credits presented higher effect in the feasibility of biogas energy production. [10] on a study about the feasibility of energy production with bovine residues, verified that the payback period, with the use of residual heat produced in the biodigester, is 3.7 years. Analysis based on the LPV model produce useful information for the development of a biogas unit. It can be extended to incorporate and treat doubts concerning methane yield, subsidies and biodigester prices.

5. Conclusions

The production of electric energy having as its source biogas originated from swine culture is not financially feasible. It becomes economically feasible when there is income with the sale of carbon credits.

As for the Payback period, one can conclude that when energy production happens either 16 or 20 h day^{-1}, the payback period remains almost the same. That happens because the initial investment for the production of energy, generating 20 h day^{-1}, is elevated. In that sense, it is suggested that the producer should generate only 16 h day^{-1}, due to the fact that the initial investment is lower.

The cost of electric energy production becomes competitive (without the sale of carbon credits) when the payback period is over 15 years, generating energy at least 16 h day^{-1}. When carbon credits are sold, from a payback period of 10 years on and generating 10 h day^{-1}, the production cost becomes feasible to the producer, providing income with the sale of the exceeding electric energy.

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